

AN ASSESSMENT OF FLIGHT CREW EXPERIENCES WITH FANS-1 ATC DATA LINK

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ABSTRACT

Researchers from NASA and ASRS are working with representatives from airlines, manufacturers, pilot unions, and other international safety organizations to evaluate the flight crew's experiences using the FANS-1 controller-pilot data link communication (CPDLC) system. The goals of this human factors evaluation are to develop recommendations for improvement of FANS-1 CPDLC and to provide "lessons learned" that can guide development of future CPDLC systems. There are three parts to this project: (1) collection and analysis of pilot reports related to usage of FANS-1 CPDLC through NASA's Aviation Safety Reporting System, (2) collection of survey data from pilots who are currently using the system, and (3) a task analysis-based usability evaluation of the FANS-1 data link system. This paper will describe the status of each of these project elements.

INTRODUCTION

Background

FANS-1 CPDLC. The Future Air Navigation System, or FANS-1, is the first avionics system to provide direct controller-pilot data link communication (CPDLC). Communications supported by FANS-1 CPDLC include air traffic control clearances, pilot requests, and position reporting. FANS-1 CPDLC went on-line in 1995, with three international air carriers purchasing FANS-1 equipment for their Boeing 747-400 aircraft. Five air traffic service facilities that control the South Pacific en route airspace have been providing full CPDLC services to these aircraft, with two international data link companies supporting the data link communications of both airborne and ground-based systems. FANS-1 CPDLC has been in continuous use in the South Pacific oceanic airspace for over three years.

Other operational pilot-controller data link systems. In addition to FANS-1 CPDLC, an ACARS (Aircraft Communications Addressing and Reporting System) package also supports ATC-to-aircraft data link communication in oceanic airspace. In contrast to FANS-1 CPDLC, the ACARS system uses a radio operator as an intermediary who relays messages

between air and ground. This system is about to be discontinued.

Current expansion of FANS-1 CPDLC. The population of both air and ground users of FANS-1 CPDLC has begun increasing rapidly. More aircraft are or will soon be certified for FANS CPDLC communications, including Boeing's 777, 757/767 and MD-90; and Airbus's A319/320/321 and A330/340. Tokyo Center and Oakland Center have begun to provide FANS-1 CPDLC services on central and northern Pacific routes, and at least 8-10 additional international carriers will soon be using FANS-1 CPDLC on their 747-400 and 777 aircraft.

NASA's Interest

As part of NASA's Terminal Area Productivity program, researchers at NASA Ames Research Center have been investigating the possible use of CPDLC in the domestic terminal environment to exchange route information and clearances between an aircraft's flight management system and ground-based air traffic controller decision support tools (the Center TRACON Automation System) (Palmer, 1999).

An ASRS database search for background information on pilot controller data link found several incident reports describing problems related to its use for ATC clearance communication. Four of these reports involved the use of ACARS data link, and four involved use of FANS-1 CPDLC. We felt that investigating the problems encountered by current data link users could provide insights for the appropriate design and use of CPDLC systems, not only for NASA's project, but for other CPDLC development efforts. This "lesson learned" investigation might also identify opportunities to improve FANS-1 CPDLC itself, and give new users of the system a chance to learn from the experiences of others.

PROJECT OVERVIEW

A collaborative working group, the "FANS Interoperability Team" (or FIT) was already addressing technical and operational issues associated with FANS use when we began this project. We chose to focus on a human factors evaluation of flight crew experiences with the system. Since publicly available information describing those experiences was limited to 4 ASRS incident reports, our first goal was to gather more information.

Data Collection

In July 1998, the Aviation Safety Reporting System (ASRS) issued a request for pilots to submit reports describing any interesting incidents or events they had experienced that were related to use of FANS-1 CPDLC, regardless of the operational significance of the event. Many of the pilots who submitted reports were also asked to participate in a 'callback' telephone interview. ASRS has had excellent success using this kind of outreach effort in the past to investigate wake turbulence incidents and turbojet upsets (ASRS, 1996).

We were concerned, however, that this ASRS outreach might only elicit reports from pilots who either had 'incidents' to report, or who had very strong feelings about the system. In order to get a broader sample of user experiences, we developed a fleet survey that would complement the ASRS effort. The survey would reach a wider segment of the user population, and allow us to balance the detailed narrative descriptions of single events provided in incident reports with a structured questionnaire designed to obtain data characterizing the full range of flight crew experiences with the system. This survey is being distributed to all of the Boeing 747-400 pilots who fly with three major international carriers.

Usability Evaluation

A task description was developed for the set of pilot activities associated with normal operation of the FANS-1 CPDLC system. The task description was used as the basis for a cognitive walkthrough usability evaluation of the system (Polson & Smith, 1999). This evaluation served as a starting point for development of the 747-400 operators' fleet survey.

Each of these three project efforts—the ASRS callback project, the fleet survey and the usability evaluation—will be described in more detail below. First, however, the kind of problems pilots are experiencing while using FANS-1 CPDLC will be illustrated by describing an incident reported to ASRS in 1996. Note that this particular report and others like it have already been the subject of extensive analysis and discussion, resulting in recommended changes to both air and ground operator procedures, and to the uplink presentation format (J. Crane, personal communication, 29 January 1999).

EXAMPLE 1: FLIGHT CREW MISUNDERSTANDING OF A CONDITIONAL ALTITUDE CLEARANCE

The following narrative is from an ASRS incident report that was filed by the flight's captain:

<input type="checkbox"/>	1234Z	ATC UPLINK	1/2	<input type="checkbox"/>
<input type="checkbox"/>			STATUS	<input type="checkbox"/>
<input type="checkbox"/>			OPEN	<input type="checkbox"/>
<input type="checkbox"/>		CLEARED DIRECT 1510N 150W,		<input type="checkbox"/>
<input type="checkbox"/>		DIRECT 12N 156W, DIRECT		<input type="checkbox"/>
<input type="checkbox"/>		05N 164W		<input type="checkbox"/>
<input type="checkbox"/>		-----CONTINUED-----		<input type="checkbox"/>
<input type="checkbox"/>		REPORT>		<input type="checkbox"/>

<input type="checkbox"/>	1234Z	ATC UPLINK	2/2	<input type="checkbox"/>
<input type="checkbox"/>	/AT			<input type="checkbox"/>
<input type="checkbox"/>	N15°10.0 W150°00.0			<input type="checkbox"/>
<input type="checkbox"/>	CLIMB TO AND MAINTAIN			<input type="checkbox"/>
<input type="checkbox"/>	FL350			<input type="checkbox"/>
<input type="checkbox"/>	/RPT REACHING			<input type="checkbox"/>
<input type="checkbox"/>	FL350			<input type="checkbox"/>
<input type="checkbox"/>	<STANDBY			<input type="checkbox"/>
<input type="checkbox"/>	<REJECT	ACCEPT>		<input type="checkbox"/>
<input type="checkbox"/>	-----			<input type="checkbox"/>
<input type="checkbox"/>	<PRINT	LOG>		<input type="checkbox"/>

Figure 1. A recreation of the ATC Uplink CDU pages described in Example 1.

"We were 3200 lb behind our flt plan fuel forecast, and because of acf reluctance to clb, I requested an off course clb to FL350, a more efficient alt for us. The following clrc was received from ATC, 'clrd direct 1510N 150W, direct 12N 156W, direct 05N 164W, at 150W clb and maintain FL350, rpt reaching FL350.' ... We both somehow missed the 'at 150W' restriction and began a clb to FL350 on the new heading. After rptng level at FL350 we received a message from ATC, 'your clrc was to clb at 150W, not before, verify alt.' We were both surprised by this message..."

The captain goes on to describe what the crew did, then speculates about what might have led them to overlook a crucial part of the clearance:

"I feel several factors contributed to the error. [1:] Both the FO and I had little actual experience using FANS since our original training in late 1995, and this was our first time seeing the ATC uplink clrc format. [2:] The new clrc was quickly accepted using the accept prompt, this action changed the screen to the verify response page, and diverted us from the print prompt which should have been selected before sending the accept message. [3:] If just the CDU screen is used to read the clrc, the critical word 'at' is in small font, and very easy to overlook with dim screens and tired eyes. [4:] The correct operational procedure is to 'print and read aloud' and had we followed the proc, the incident would not have occurred. [However,] nearly 1 yr has elapsed since initial FANS training... This long period of time without actual hands on experience... presents an opportunity for procedural errors." (ASRS #344041)

The captain identifies four contributing factors: (1) crew unfamiliarity with the data link interface, (2) disappearance from view of the 'print' prompt (and the 'at 150W'

phrase) when the CDU page changes, (3) mixed font formats that make the short word 'at' even harder to notice, and (4) a long interval (roughly 10 months) between training and initial use that made trained procedures difficult to remember.

One additional factor was not apparent to the captain. Nor was it apparent to anyone else, until a few additional incidents were reported. The flight crew had asked for (and were eager to receive) a climb clearance. They were not expecting the conditional restriction "at 150W" that delayed the clearance to FL350, and overlooked it when reading the ATC uplink message on the CDU.

Although conditional clearances may also be misunderstood or forgotten in voice communications, the readback requirement and opportunity for the controller or radio operator to emphasize the conditional restriction make it less likely that an error will occur.

Perhaps the most interesting thing about this example is that the significance of the conditional element in this data link clearance was not recognized until a number of similar incidents had occurred. System designers, message set developers, human factors analysts, fleet training personnel, and trained flight crews did not detect or immediately recognize the vulnerability of conditional elements in data link clearance messages. This was a 'lesson' waiting to be 'learned' from operational experience, and one whose solution is still being worked out.

ASRS INCIDENT REPORTS & CALLBACK INTERVIEWS

The example just cited demonstrates the importance of incident data in identifying and understanding the operational problems that can occur after the introduction of new technology.

An ASRS announcement of NASA's interest in obtaining more FANS-1 related reports was released in July 1998. As mentioned earlier in this paper, 8 ATC data link related incident reports (4 FANS-1 and 4 ACARS data link) had been received before July 1998. An additional 17 reports were received between August 1998 and March 1999. Of these 17 filed reports, 6 described FANS-1 related incidents that had not been previously reported, and 2 described previously unreported ACARS incidents. The remainder of the new reports include: three providing non-incident related pilot feedback, five duplicate descriptions of the same incident, and one description of an incident that occurred in 1996. Table 1 categorizes all of the reports received by ASRS between 1993 and March 1999 that refer to the use of data link for pilot-controller communication.

Table 1. ASRS Reports filed between August 1993 and February 1999 that referred to controller-pilot data link

<u>Report Category</u>	<u>Count</u>
<i>(incidents involving use of FANS-1 CPDLC)</i>	
flight crew misreads conditions of clearance	4
data link message is confusing	3
latitude or longitude coordinates misread	1
incorrect flight# entry; clearance issued to wrong a/c	1
FANS-1 CPDLC related workload problem	1
<i>(other incidents and reports)</i>	
incident involved use of ACARS data link	6
pilot comments about FANS-1 CPDLC	4
FANS-1 usage unrelated to reported incident	2
duplicate reports filed by multiple crew members*	5

*Duplicate reports are *not* included in other category counts

As indicated above, a number of ASRS reports have been filed describing incidents that involved use of ACARS data link for pilot-ATC communication. Their presence demonstrates that controller-pilot data link problems are not unique to the 747-400 FANS implementation; in fact, the problems flight crews reported with ACARS data link were similar to those that occurred with FANS-1 CPDLC. The next example is taken from an ACARS incident report.

EXAMPLE 2: SIGNIFICANCE OF "ACCEPT" AND "REJECT" AS DATA LINK RESPONSE LABELS

This flight was cleared for a block altitude from FL290 to FL330. After 3 hours the crew was asked to "say time able FL350". Shortly after responding to this message, the aircraft received the following clearance by data link.

"At xxxzZ we received the following satellite com message... 'xxx ATC clrs acr x dsnd to and maintain FL310 rpt reaching. Dscent necessary due to opposite direction company tfc.' ... the ACARS provided 2 prompts 'accept' or 'reject' [for response to this message]. The way it is presented to the plt makes it seem that you do have an option. The lower alt was unfavorable...and because we were down on our fuel score I... felt that I needed to reject the clrc...A few minutes later we were selcaled...They wanted to know why we didn't want to dsnd. I told them because of fuel burn concerns... In the meantime, we started to reevaluate the higher alt."

In an ASRS callback interview, the reporter again tells the analyst that:

"He believed the ACARS machine (data link) gave a clrc which could be accepted or rejected because that is what the options were on the selection menu of the aircraft's receiver" (ASRS #303614).

	12:34	ATC CLEARANCE	
	12:32	OPEN	01/02
<input type="checkbox"/>	XXX ATC CLEARS FLT999		
<input type="checkbox"/>	DESCEND TO AND MAINTAIN		
<input type="checkbox"/>	FL310 REPORT REACHING. DESCENT		
<input type="checkbox"/>	NECESSARY DUE TO OPPOSITE		
<input type="checkbox"/>	DIRECTION COMPANY TRAFFIC.		
<input type="checkbox"/>			
<input type="checkbox"/>	*REJECT		ACCEPT*
<input type="checkbox"/>	<RETURN		

Figure 2. Recreation of ACARS display described in Example 2.

The captain certainly has the authority to reject any clearance he feels is unsafe, and his concern about fuel burn gave him a good reason to reject the descent clearance. So it's interesting to note that he suggests—not once, but twice—that the labels on the prompts for responses influenced his decision.

This report demonstrates how important interface labeling can be in shaping a pilot's conception of a task and the options available for its completion. The cognitive walkthrough methodology (described later in this paper) is an interface inspection method that helps system developers identify and explore the consequences of these meaningful labels in a task interface (Polson & Smith, 1999).

The example also shows how standard message formats, interface labels, and transmission delays might distort communication between the pilot and controller in the data link message exchange. In this case, the captain apparently felt that the controller had offered him a choice of accepting or rejecting the descent clearance. And the controller may have felt the captain was being uncooperative—refusing to either climb or descend from his current altitude.

Finally, the report illustrates some of the unintended side effects of changing from voice to data link for pilot-controller communication. One of these consequences is increased difficulty in conducting any dialog or negotiation that requires more than a simple question-reply exchange.

TASK ANALYSIS

A task analysis was performed to develop a description of each routine task that a pilot might perform while using FANS-1 CPDLC in the 747-400. The analysis covered: (1) preflight initialization tasks; (2) tasks performed to establish or maintain a CPDLC connection (logging on, monitoring connection status, facility handoff monitoring); (3) message exchange tasks (responding to ATC uplinks, sending requests to

ATC, sending position reports to ATC). Each task's description included the following:

- a statement of the task's **purpose**
- **task timing or pre-conditions** that determine when the task should be performed
- **where** the task is performed—a description of the system interface used to accomplish the task
- a hierarchical description of **subtasks and actions**
- system **cues or feedback** to support task performance
- **information requirements** for task completion
- the **consequences of incorrect performance**

Figure 3 shows part of the description of the task 'Respond to ATC Uplink Messages'. The subtask shown in the figure is 'Detect Uplink Message', which is cued by (1) a message on the EICAS display, coupled with (2) an aural chime. FANS-1 system documentation (Honeywell, 1996) and the South Pacific Operations Manual (1997) were used to complete the task descriptions. In addition, several 747-400 pilots reviewed the material as it was developed.

Cockpit Cognitive Walkthrough

The Cockpit Cognitive Walkthrough usability inspection method is described in a companion paper in these Proceedings (Polson & Smith, 1999). A design team uses this method to 'walk through' a storyboard representation of the series of system interface changes that precede and follow each action a pilot will take in performing a task, evaluating the adequacy of the interface in supporting correct performance at each step.

The walkthrough focuses on the role of interface labels, prompts and feedback in influencing the pilot's execution of a task. This methodology works on the assumption that task performance in the cockpit can often be described as 'performing by exploration'—a problem solving process guided by knowledge of the task to be performed, of how to execute related tasks, and of the task's interface conventions (Polson & Smith, 1999). There is a large amount of evidence that good interface labeling and feedback are critical to successful exploratory task performance, both in the office automation domain (Kitajima & Polson, 1997; Wharton et al., 1994), and in the modern glass cockpit (Polson, Irving, & Irving, 1995).

The task description was used to conduct a cognitive walkthrough-like assessment of the support that is provided to pilots by the FANS-1 CPDLC system interface when they perform routine data link tasks. The task description lists subtasks, required actions, interface descriptions, cues and feedback—all of the inputs used to conduct a cognitive walkthrough.

task: RESPOND TO ATC UPLINK MESSAGES

where: FMC CDU, ATC Uplink page, Verify Response page; other FMC pages affected by loadable uplink elements, or accessed in response to ATC request.

when: a/c receives CPDLC message from ATS facility

subtasks: 1. detect uplink message

cue: "ATC Message" appears on EICAS display, accompanied by aural chime.

2. access and review message

...

Figure 3. Portion of task description for ATC clearance handling while using FANS-1 CPDLC in the Boeing 747-400.

One difference between the assessment of FANS-1 CPDLC and the walkthrough methodology as described by Polson and Smith is that this assessment was performed by one individual instead of a design team. One strength of the cognitive walkthrough is that it provides a means for bringing the knowledge, experience and insights of an interdisciplinary team to the design review process. Although the walkthrough of FANS-1 CPDLC was conducted by only one of the authors, that individual had many discussions with others in the group—including researchers with extensive knowledge of prior work investigating the use of data link for controller-pilot communication (Lozito, et al. 1993; SAE International, 1995), and pilots with relevant operational experience. Furthermore, refinement of the fleet survey that was developed from the walkthrough analysis was an iterative process involving most of the project team.

The following are examples of questions asked in the walkthrough analysis of each FANS-1 CPDLC task:

- Will it be clear to the pilot when the task should be performed?
- Is each action clearly prompted?
- Are there any apparent, competing alternatives to the correct action?
- Is adequate feedback provided about the outcome of each action?
- Are any *incorrect* actions available?
- Do the actions need to be performed in a specific order? and, is it possible to perform them out of sequence?
- Was any information needed to complete an action; if so, was it readily available?

This critique formed the basis for the fleet survey that comprises the third element in this project. Figure 4 shows a few questions from the fleet survey that resulted directly from the walkthrough analysis of the subtask 'detect uplink message' (shown in Figure 3).

FLEET SURVEY

In addition to interface-related questions derived from the walkthrough, the survey addresses the following:

- What elements of FANS-1 CPDLC are flight crews using?
- What do they like about it?
- Where are they having problems?
- Where is the task interface problematic?
- How well are company training and documentation preparing them to use the system?

Most of the survey consists of task-related multiple-choice questions. It also includes an open response section, and a section that asks pilots to compare several different methods for ATC communication. Results from the survey should be available sometime later this year, and can be obtained by contacting Nancy Smith at nsmith@mail.arc.nasa.gov.

CONCLUSIONS

Although the focus of this paper has been on exploring problems encountered with use of FANS-1 CPDLC, early survey results indicate that pilots find it a great improvement over HF voice for most oceanic communications with air traffic control. The discussion below offers some preliminary lessons that can be learned from operator experiences with the system. However, it is definitely not our intent to suggest that CPDLC is inferior to voice for pilot-controller communication.

Some "Lessons Learned"

The two reported ASRS incidents demonstrate some of the negative side-effects of changing from voice to data link for pilot-controller communication: conducting a dialog becomes more difficult; absence of readback opportunities removes an important error trapping mechanism; intent communication can be affected by the mechanics of data link. The importance of the system interface in data link communication was also demonstrated:

Detecting the FANS Clearance:

27. The aural chime announcement of a FANS ATC uplink message is:
- | | | | | | |
|----------|-----|-----|-----|-----|------------|
| Clear | ___ | ___ | ___ | ___ | Confusing |
| Adequate | ___ | ___ | ___ | ___ | Inadequate |
28. Have you ever been on a flight when a FANS ATC uplink message was not detected as soon as it arrived?
- ___ Never ___ 1-2 times ___ 3-9 times ___ 10+ times ___ Don't know
29. If so, how was the message eventually noticed? _____
30. Which of the following creates the most difficulty in detecting an ATC message?
- ___ the chime is associated with other events besides the ATC message
___ the EICAS display does not reflect the number of open ATC messages
___ it isn't difficult
___ Other _____

Figure 4. Four of the questions from NASA's FANS-1 CPDLC Fleet Survey for Boeing 747-400 pilots.

message presentation format and function labels played a significant role in both ASRS incidents.

Standard phraseology and voice communication protocols are replaced in data link by standardized message sets (often based on voice phraseology) and new interface conventions. As both examples show, data link messages are not directly equivalent to voice clearances, and attempts at direct translation cannot guarantee that safeguards evolved over years of radio voice communication will successfully transfer to data link. Both examples demonstrate that new problems are encountered with data link communication and different safeguards must be developed.

Recommendations

A key factor in identifying and solving the problems encountered by CPDLC users is access to accurate and detailed descriptions of those problems. System operators are encouraged to use the available confidential reporting mechanisms to describe their experiences so that the problems they encounter can be thoroughly analyzed and the system improved. Submission of such reports should not divert crews from submitting reports to their airlines in support of FANS Interoperability Team efforts to improve the system as a whole.

ACKNOWLEDGEMENTS

We want to thank Captains Michael Cuddy and John Powers of United Airlines, Jean Crane of the Boeing Commercial Airplane Group, and our colleagues Captain Paul Buchanan, Linda Connell and Rowena Morrison of the Aviation Safety Reporting System, all of whom were extremely generous with their time and support.

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